



Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at <http://about.jstor.org/participate-jstor/individuals/early-journal-content>.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

Mechanics of movement in *Drosera rotundifolia**

HENRY D. HOOKER, JR.

CONTENTS	
I. INTRODUCTION.....	389
II. EXPERIMENTAL DATA.....	389
1. OSMOTIC CONCENTRATION.....	389
2. RABDOIDS.....	393
3. UNBENDING BY PLASMOLYSIS.....	394
III. DISCUSSION.....	394
1. INCREASED TURGIDITY AS THE MEANS OF MOVEMENT.....	394
(a) <i>Osmotic concentration</i>	395
(b) <i>Permeability</i>	397
(c) <i>Cell-wall elasticity</i>	397
2. COMPARISON WITH GEOTROPIC MOVEMENTS.....	398
3. ALTERATION OF CELL-WALL ELASTICITY.....	399
4. AUTOTROPIC NATURE OF UNBENDING.....	400
(a) <i>Comparison of autotropic with hydrotropic stimulus</i>	400
(b) <i>Internal changes that follow bending</i>	400
IV. SUMMARY.....	402

I. INTRODUCTION

Plant growth is defined technically as any permanent change of shape or size produced by the activity of the plant (*cf.* Jost, '13, p. 339; Pfeffer, '06, p. 1). The movements of *Drosera* tentacles, being reactions to stimuli, are determined by the activity of the *Drosera* plant. Moreover, bending is accompanied by a permanent elongation of the convex side of the tentacle and unbending by a corresponding increase in the length of the concave side (Hooker '16). These movements are therefore phenomena of growth. The term "growth" obviously includes a number of processes, which may be determined by changes in the amount of protoplasm, cell-wall material or osmotically active substances.

II. EXPERIMENTAL DATA

I. OSMOTIC CONCENTRATION

In order to obtain a more detailed knowledge of the growth which brings about the movement of *Drosera* tentacles, the con-

* Contribution from the Osborn Botanical Laboratory.

centration of osmotically active material dissolved in their cells was measured by plasmolysis. For this purpose solutions of potassium nitrate and glucose were prepared. The osmotic concentration of plant cells may be compared with the concentrations of these substances in terms of their relative osmotic values. Consequently osmotic concentrations will be measured in atmospheres as follows:

Atmospheres	Solutions of KNO ₃ in percentages	Solutions of glucose in percentages
5.....	1.43.....	3.85
6.....	1.71.....	4.62
7.....	2.00.....	5.40
8.....	2.29.....	6.17
9.....	2.57.....	6.95
10.....	2.86.....	7.71
11.....	3.14.....	8.48
12.....	3.43.....	9.25
13.....	3.71.....	10.02
14.....	4.00.....	10.80
15.....	4.29.....	11.58

Tentacles of the *Drosera* were removed from the leaf with forceps, placed in prepared solutions, mounted and examined under the high power of the microscope. Plasmolysis was found to be most readily detected in slightly pigmented cells, and whenever possible tentacles with stalks composed of such cells were selected. In case aggregation occurred, the first traces of plasmolysis were much more difficult to make out. Tentacles were treated and examined when straight; just after bending in response to a tactile stimulus; when fully bent; during unbending; and when again straight. The first procedure was to place tentacles in each of the prepared potassium nitrate solutions and to examine them for traces of plasmolysis. The results obtained by this general orientation were repeated and verified by numerous subsequent experiments both with potassium nitrate and with glucose solutions. The data given with glucose solutions were practically identical throughout with the results furnished by the potassium nitrate solutions. The final data given below are expressed in terms of the most concentrated solution that failed to plasmolyze.

The epidermal cells on the pedicels of the tentacles have strongly cutinized outer walls which are impermeable to salt and sugar solutions. The solution reaches the inner cells of the ten-

tacle by way of the gland at the apex and the broken end at the base where the tentacle was formerly attached to the leaf blade. In many cases it was found necessary to puncture the cuticle in several places with a needle, or else to cut the pedicel into segments with a razor, in order to give the solutions access to all the cells of the tentacles.

1. *Straight tentacles*.—Examination of over thirty normal marginal tentacles with potassium nitrate and of twenty with glucose solutions showed the cells of the apical half of the pedicel to have a higher osmotic concentration than the cells of the basal half. The latter ranged from eight to nine atmospheres; the former from nine to eleven. In a few instances the cells on the dorsal and ventral surfaces of the basal portion of the pedicel had a higher osmotic concentration than the cells on the flanks. De Vries ('86, pp. 4, 5) found that the cells of *Drosera* tentacles were plasmolyzed by a three per cent. solution of potassium nitrate, but not by a two per cent. solution. This is seen to hold for all the stalk cells excepting those at the apical end just below the gland.

2. *Bending tentacles*.—The glands of numerous tentacles were stimulated by rubbing with a fine brush and after fifteen to twenty minutes, when the tentacles had bent through an angle of 90° to 120° , they were removed and placed in a two per cent. potassium nitrate solution. This treatment did not cause the tentacles to unbend. They were then mounted in some of the same solution and covered with a supported cover-glass. Since the tentacles were curved, the different effect of the solution on the convex and concave sides of the tentacle could be observed. In nearly all cases where the movement was rapid, the two per cent. potassium nitrate solution had plasmolyzed the cells in the bent region on the convex or abaxial side, while the cells on the concave or adaxial side showed no effect. Similar results were obtained by using a 5.4 per cent. glucose solution. Examination of fifty tentacles with potassium nitrate and of thirty-five with glucose showed the osmotic concentration in the abaxial cells to be from six to eight atmospheres, in the adaxial cells from eight to nine atmospheres. The osmotic concentration of the cells on the convex side had therefore diminished during bending; that of the cells on the concave side

had remained practically unchanged. The greatest diminution in the osmotic concentration of the cells on the convex side was observed in those tentacles that reacted most rapidly. In a few cases of exceptionally slow movement no diminution was observed, the osmotic concentration being either eight or nine atmospheres. The osmotic concentration of the cells in the upper half of the stalk was found to be the same as in the unbent tentacle.

3. *Bent tentacles*.—Tentacles were stimulated by placing small flies on their glands, and after bending had proceeded as far as possible the tentacles were removed and examined. In twenty-five tentacles treated with potassium nitrate solutions and fifteen tentacles treated with glucose solutions, the cells at the base of the pedicel and in the bent region had an osmotic concentration of nine to eleven atmospheres, there being no difference between the two sides of the tentacle. The cells of the apical portion of the pedicel were found to have an osmotic concentration of ten to thirteen atmospheres. In a few exceptional cases the cells in the latter region appeared to have a higher osmotic concentration, but the detection of plasmolysis was particularly difficult because these cells were smaller than the basal cells and their contents were strongly aggregated.

4. *Unbending tentacles*.—Twenty tentacles in process of unbending were examined with potassium nitrate solutions and the results were checked by the examination of twelve more with glucose solutions. The osmotic concentration of the cells in the basal half of the pedicel was from eight to ten atmospheres; in the apical half from nine to eleven. No difference was observed in the osmotic concentrations of the cells on the concave and convex sides.

5. *Unbent tentacles*.—Eighteen tentacles which had become straight after completing a reaction were examined and found to be similar in osmotic concentration to the normal tentacles before reaction.

The experimental data given above are summarized in the following table:

Three significant facts should be noted, namely:

1. The osmotic concentration of the pedicel cells increases from the base to the apex.

Tentacles	Straight	Bending	Bent	Unbending	Unbent
Basal half of pedicel:					
Abaxial side	8-9	6-8	9-11	8-10	8-9
Adaxial side	8-9	8-9	9-11	8-10	8-9
Apical half	9-11	9-11	10-13	9-11	9-11

2. During rapid bending the osmotic concentration of the abaxial cells in the growing region decreases.
3. When the tentacles are bent, the cells have a higher osmotic concentration than at any other time.

2. RABDOIDS

Rabdoids were first discovered by Gardiner ('85) in *Drosera dichotoma*, and he states that in *Dionaea*, *Drosera rotundifolia* and other species of *Drosera* rabdoids occur which resemble those of *Drosera dichotoma*. Gardiner described the rabdoid as a body, usually spindle-shaped or acicular, which occupies such a position that it stretches diagonally across the cell from end to end, the two extremities being imbedded in the cell protoplasm. They were present in all the epidermal cells of *Drosera dichotoma* leaves except the gland cells and the cells immediately beneath the glands. In the bending region of those tentacles capable of movement they were larger in the epidermal cells on the abaxial side than on the adaxial side where they were very small or apparently absent. When these cells lost their turgidity the rabdoids contracted and separated into two or more parts, but regained their spindle shape when turgidity was restored. A sudden blow on the cover glass also caused the rabdoids to assume a spherical form.

The presence of rabdoids in the epidermal cells of *Drosera rotundifolia* leaves was confirmed. They occur in all the epidermal cells of the petiole, of the leaf blade and of the basal portion of the tentacles, including the bending region. Each cell contains a single rabdoid, rarely two rabdoids, situated near the outer wall and parallel with it. After a leaf has fed on insects, the rabdoids are distinctly larger than before. When plants are deprived of insectivorous food for any considerable period, the rabdoids dwindle until they are barely noticeable. Sudden shocks produced by tapping the cover glass or gradual pressure sustained for a considerable period of time cause the rabdoids to alter their shape.

They contract at each end so that they have the appearance of dumb-bells, and finally separate into several disk-shaped parts. In extreme cases they separate into a large number of droplets which exhibit Brownian movement. No marked difference was observed in the size of the rabdoids on opposite sides of the tentacle in the bending region, and no alteration was visible during movement. The function of the rabdoids is not apparent. It seems probable, however, that they are connected in some way with the process of secretion, rather than with the mechanics of movement. Gardiner ('85) suggested that they might be reserve material or some substance used up during secretion. This seems to be borne out by the fact that they are of protein composition according to Tunmann ('13, p. 481).

3. UNBENDING BY PLASMOLYSIS

Although a two per cent. solution of potassium nitrate usually plasmolyzes the cells on the convex side of a bending tentacle, this does not cause the tentacle to become straight (see De Vries, '86, p. 5). More concentrated solutions produce unbending. For a short time after the tentacle is fully bent complete plasmolysis still causes unbending, but when the tentacle has been bent a considerable period and during unbending, plasmolysis does not alter its shape.

The xylene experiment which W. H. Brown ('12, '16) made on *Dionaea* and *Mimosa* was tried on *Drosera* tentacles, but no positive results were obtained. Bent and bending tentacles were killed in boiling water, treated with 95 per cent. alcohol, absolute alcohol and xylene. No unbending ensued. This may indicate a difference between the mechanics of movement in *Drosera* and in such plants as *Dionaea* and *Mimosa*. However, the failure of the experiment may have been owing to faulty technique, although the description of the process by Brown ('16, p. 78) was followed in detail.

III. DISCUSSION

I. INCREASED TURGIDITY AS THE MEANS OF MOVEMENT

The straightening of bent tentacles by plasmolysis shows the cell elongation, which is the immediate cause of bending, to be a

passive stretching of the walls by turgidity. This conclusion is corroborated by direct observation. During bending the cells on the convex side in the curved region as seen under the microscope are noticeably distended, the outer walls appearing in optical cross-section as arcs extending between the end walls. A simple way of demonstrating this is afforded by mounting a straight tentacle in a one per cent. solution of tartaric acid, covering it with a supported cover glass and examining under the microscope. Tartaric acid as well as dilute solutions of many other organic and mineral acids induce rapid and violent bending. The acid enters the tentacle through the broken end of the pedicel at the base, where it was formerly attached to the leaf-blade, and affects the bending region directly, for inflexion proceeds even when the gland has not been stimulated in any way either by being touched or by coming in contact with the acid solution.* Gardiner ('85) observed that in well-inflexed tentacles of *Drosera dichotoma* the cells on the convex side at the bending point are very turgid. It must be borne in mind that turgidity is the external manifestation of a balance between two antagonistic factors; one factor due to the presence of osmotically active substances in solution tends to increase the volume of the cell and to stretch the wall; the other factor due to the elasticity of the cell-wall tends to compress the cell contents. An increase in the size of the cell under such circumstances follows either from an increase in the amount of osmotically active material or from a diminished elasticity of the cell-wall, unless simultaneous changes in permeability interfere.

(a) *Osmotic concentration*

The experimental data show that during bending the osmotic concentration in the cells on the abaxial side of the pedicel in the growing region falls from eight or nine to six or eight atmospheres. It is at once evident that the elongation of the cells is not the result of an increase in the amount of osmotically active material. Exact data concerning the increase in length of the abaxial side

* The bending produced in detached tentacles by this means is frequently astonishing. The tentacle may bend around completely on itself until it forms a spiral. It is known that stimulation of the glands of *Drosera* tentacles is followed by the secretion of an acid. Is it possible that the impulse which is conducted from the gland down the pedicel to the base of the tentacle and which there starts movement is the acid secreted by the gland diffusing from cell to cell?

during bending is given in a previous paper (Hooker, '16). An average of eleven measurements taken in the region of most active growth shows the increase to be about 27 per cent. of the original length. In one typical example (*ibid.* f. 6), cells on the abaxial side (*ibid.* Table III, segment 5) in the bending region grew from 0.45 mm. to 0.57 mm., an increase of 26.6 per cent. Assuming the other dimensions of the cell to remain unaltered, the increase in volume of the cells in this region would be proportional to the increase in length. An increase in volume must be accompanied by a corresponding decrease in osmotic concentration. Thus if the original concentration were eight atmospheres, we should expect as the result of an increase in volume of 26 per cent. an equivalent decrease in osmotic concentration, that is a fall from eight to six atmospheres. When it is considered that the measurements of osmotic concentration were taken before bending was completed, and that soon after the tentacle is bent the cells restore their original osmotic concentration, a process that must commence soon after bending begins, we see that the maximum decrease in osmotic concentration observed is amply accounted for by the increase in volume of the growing cells. The maximum decrease observed was approximately 25 per cent.; the increase in length averaged 27 per cent.; the correspondence is well within the limits of probable error. The alteration of osmotic concentration is therefore a result of the growth of the cells, and not a determining factor of their elongation.

No marked change in the osmotic concentration of the cells on the adaxial side of the bending tentacle was observed at any time. The slight elongation or compression which these cells experience during bending is probably insufficient to make a change of osmotic concentration perceptible. The irregularity in the nature of the alterations on the concave side of the tentacle indicates that this side takes no active part in the bending, but is either stretched or compressed according to the mechanical conditions that happen to prevail in the base of the pedicel. Gardiner ('85) states that the cells on the concave side of well-inflected *Drosera dichotoma* tentacles lose their turgidity at the bending point. No distinct evidence of loss of turgidity by the cells on the concave side of inflected *Drosera rotundifolia* tentacles was observed, however.

The external walls appear in optical cross-section as straight lines extending between the end walls.

(b) *Permeability*

It is of course possible that the elongation of the cells on the convex side of inflected tentacles might be caused by increased osmotic pressure, if the detection of the increased osmotic concentration were rendered impossible by a simultaneous increase in the permeability of the cells to the plasmolyzing solutions. The possibility that such is the case here is ruled out by two considerations. Firstly, the determinations of osmotic concentration made with an electrolyte, potassium nitrate, were confirmed by determinations made with a non-electrolyte, glucose. It is highly improbable that there should occur a differential change in permeability of such a nature as to permit increased diffusion of both potassium nitrate and glucose, which at the same time would not permit increased diffusion of the osmotically active material within the cell. Secondly, the correspondence between the increased volume of the elongating cells and the decreased osmotic concentration indicated by experiments cannot be disregarded, since it offers a direct and simple interpretation of the experimental data.

(c) *Cell-wall elasticity*

Since there is no evidence that the permeability is altered, and since the osmotic concentration decreases during bending, the increased turgidity of the elongating cells must be due to a decrease in the elasticity of their cell-walls. It is evident that irreversible changes take place in the cell-wall, for the increased size of the cell-wall is soon rendered permanent, probably by the deposition of new cell-wall material. This is shown by the fact that after bending is completed, the cells on the convex side lose their excess turgidity. The distended outer walls become flat, yet the tentacle remains bent. At this stage plasmolysis no longer causes unbending. Gardiner ('85) states that in *Drosera dichotoma* the cells on the concave side not only lose their turgidity after bending is finished, but become flaccid. These irreversible changes in the cell-wall apparently begin soon after bending starts, for when a bending tentacle is forcibly straightened, the distended outer

cell-walls do not always return to their original condition, but are frequently crumpled or wrinkled. The rate of change in the cell-wall properties undoubtedly increases during the inflexion. In the same way the decrease in osmotic concentration which results from the increase in volume of the elongating cells is soon compensated for by the formation of new osmotically active material, as is shown by the equality of osmotic concentration on opposite sides of the tentacle a short time after it has become fully bent. This process too is probably initiated soon after inflexion begins, with the result that no marked difference in osmotic concentration is noticeable on opposite sides of tentacles which bend slowly. In the last analysis, therefore, the growth which causes the inflexion of *Drosera* tentacles is the activity of the protoplasm in manufacturing cell-wall substance and osmotically active material.

2. COMPARISON WITH GEOTROPIC MOVEMENTS

The movement of *Drosera* tentacles is seen to be brought about by the same mechanism found in geotropically reacting organs, where Kraus ('82, p. 87) and Noll ('88, p. 511) observed a decrease in the osmotic concentration of the cells on the convex side of roots and stems, which was particularly evident in case of rapid bending. The subject is well summed up by Jost ('13, p. 580) in the following paragraph, and his remarks apply to the bending of *Drosera* tentacles with equal felicity:

In all cases that have been more carefully studied, the immediate cause of the bending is a difference of growth in length on opposite sides. The surface growth of the membranes here as elsewhere is preceded by stretching due to turgidity, and this is gradually made permanent by growth. If an organ be plasmolyzed at the beginning of the geotropic bending it again becomes straight, but later the curvature is permanent. The stretching is unequal in amount on the two opposite sides. This difference might consist in an increased osmotic pressure on the convex side and diminished osmotic pressure on the concave side, but this is by no means the case; the pressure on the concave side seems rather to remain unchanged, while that on the convex side diminishes during bending. This result is not so astonishing when we consider that the rate of growth does not depend directly on the amount of osmotic pressure, but that this latter frequently depends on the increase in cell-volume. The unequal stretching of the opposite sides due to turgidity must therefore be connected with an alteration in the elasticity of the cell-walls, the convex side becoming more extensible. Of course in unicellular organs (in sporangiophores of the Mucorineae, for example), the bending must depend solely on a change in the elasticity of the cell-wall.

3. ALTERATION OF CELL-WALL ELASTICITY

In the opinion of Noll ('95, p. 65) the change in the plasticity of the cell-wall is analogous to the gradual change that takes place in a strung bow, which after having been left strung a long time does not return completely to its original shape when unstrung. This plastic change does not involve any permanent diminution of elasticity, however, for the bow returns to its new shape after bending. The source of energy for this change in plasticity is found in the stored energy of elastic tension. The change from a condition of elastic tension to a plastic alteration of shape is compared by Noll ('95, pp. 79-81) to changes produced in rubber by vulcanization, during which process any elastic deformations that happen to be present are transformed in a greater or less degree to permanent alterations of shape. In bending plant organs he assumes that the protoplasm secretes one or more substances which act on the cell-wall as vulcanizing sulphur acts on crude rubber.

The correlation between the molecular structure and the physical properties of metals, which has been discovered in recent years by metallographists, offers a more satisfactory interpretation of the changes in the physical properties of the cell-wall. The alteration of the strength, ductility and elasticity of metals produced by mechanical treatment and by heat are based on changes in molecular structure, which consist in the rearrangement of the relative amounts of the phases that enter into the composition of the metal. Two phases are usually present, a crystalline phase and an amorphous phase that cements the crystals together. The strength and ductility of a metal are found to be increased and the elasticity diminished by an increase in the amount of the amorphous phase and a decrease in the amount of the crystalline phase. Conversely the elasticity would be increased and the strength and ductility diminished by an augmentation of the crystalline phase and a decrease in the amorphous phase. It is probable that changes in the elasticity of plant cell-walls are also produced by alterations in the molecular structure. The cell-wall is undoubtedly a mixture of phases in heterogeneous equilibrium. It seems plausible that changes in elasticity are effected by a readjustment between these phases. Possibly an amorphous and a crystalline

phase are present, in which case an increase in the proportion of the former to the latter would decrease the elasticity and the reverse change would restore the original properties. Whatever changes in molecular structure actually occur, they must be controlled and regulated by the activity of the protoplasm.

4. AUTOTROPIC NATURE OF UNBENDING

(a) *Comparison of autotropic with hydrotropic stimulus*

When roots are exposed to a hydrotropic stimulus, greater evaporation takes place from the cells of the drier side and this tends to increase their osmotic concentration. The resulting inequality of osmotic concentration or changes which this induces on opposite sides of the root constitute the stimulus that released the hydrotropic reaction, which consists in bending toward the source of moisture by faster growth on the side with the higher osmotic concentration (Hooker, '15). It is characteristic of hydrotropic reactions that small differences in the relative moisture on opposite side of the exposed root, and consequently small differences in osmotic concentration are sufficient to produce changes that release a reaction. On the other hand the exposure must be prolonged, for the reaction does not commence until the roots have been subjected to a hydrotropic stimulus for at least six hours. Bending proceeds much more slowly than in geotropic reactions.

The autotropic unbending of *Drosera* tentacles as well as of geotropically bent roots and shoots resembles hydrotropic reactions in several respects. The unbending is produced by growth on that side of the organ that tends to have the higher osmotic concentration during bending. The reaction does not begin until some time after the bending, and it proceeds at a very much slower rate. During this process no difference of osmotic concentration was ever observed in opposite sides of the tentacle, which indicates that the formation of osmotically active material keeps pace with the increase in volume of the growing cells.

(b) *Internal changes that follow bending*

In a discussion of the autotropic unbending of tendrils, Fitting ('03, p. 612) expresses the opinion that the unbending may be a response to a new stimulus produced by "the inequality of con-

ditions, of pressure-distribution, tissue-tension, etc., which are established in the cells on opposite sides of the originally straight organ as a result of an attempted or executed reaction."

The inequality of conditions that should constitute the autotropic stimulus may be found in the changes produced by the difference of osmotic concentration observed in bending roots and tentacles, since just such a difference induces an analogous reaction in hydrotropically stimulated roots. It has been emphasized elsewhere (Hooker, '16, p. 21) that the increase in the rate of growth which produces the unbending of *Drosera* tentacles proceeds in the same manner as that which causes bending, in both cases commencing near the base and extending apically. Moreover, the amount of growth that occurs during unbending is nearly the same in amount and is distributed in much the same manner as during bending, so that the unbent tentacle is straight and reaches approximately the same position it held before the reaction. This nice regulation is intelligible when we consider that the changes resulting from the decrease in osmotic concentration during bending are directly proportional to the increase in volume of the growing cells. It is not to be denied that other factors may coöperate in producing the autotropic reaction, but the striking similarity with hydrotropic reactions indicates that the effects of the difference in osmotic concentration during bending are most significant.

When an insect is caught and digested, the unbending of the tentacle is postponed a considerable time, occasionally several days. It would appear that the absorption of food material through the gland inhibits the reaction to the inequality of conditions produced by the bending. All the cells of the tentacle from base to apex are generally aggregated while food is being absorbed. According to Gardiner ('85) the state of aggregation is accompanied by a loss of water and he found that the injection of water into the tissue stopped aggregation at once and restored the cells to their normal condition. This probably accounts for the fact that the osmotic concentration in the cells of bent tentacles is higher than under any other circumstances. When absorption ceases, aggregation stops and the tentacles unbend in the normal manner. This is brought about by increased turgidity of the cells

on the concave side. Without doubt the same factors found to determine bending are involved in the unbending, but the process is so slow that it resembles ordinary plant growth. It does not seem probable that this deferred reaction can be a direct response to changes produced by a difference of osmotic concentration which existed during bending, but is now completely effaced. In these cases unbending is probably a response to changes taking place as the result of a cessation of absorption and the end of the aggregated condition. Nevertheless the effects of the difference in osmotic concentration are conditioning factors of the unbending reaction, for an accelerated rate of growth on the adaxial side of the tentacle occurs only after previous bending.

IV. SUMMARY

The osmotic concentration in cells of *Drosera rotundifolia* tentacles was measured by plasmolysis in potassium nitrate and glucose solutions. Measurements were made on straight, bending, bent and unbending tentacles. The osmotic concentration in the cells on the abaxial side of the stalk, in the growing region, was found to diminish during bending; no change was observed on the adaxial side. The decrease in osmotic concentration is accounted for by the increase in volume of the cells, and is therefore considered an effect and not a cause of their elongation. There is no indication that changes in permeability occur.

The elongation is produced by a decrease in the elasticity of the cell-walls, and is later fixed by growth. The movement of tentacles is therefore brought about by the same mechanism found in geotropically reacting organs, where a decrease has been observed in the osmotic concentration in the cells whose growth causes bending.

Similarities between hydrotropic reactions and autotropic unbending of tentacles and of geotropically bent roots indicate that the growth on the concave side which brings about the unbending is a response to changes resulting from the difference in osmotic concentration present during bending. As in hydrotropic reactions, growth takes place on the side with the higher osmotic concentration.

LITERATURE CITED

- Brown, W. H.** ('12). The mechanism of curvature in the pulvini of *Mimosa pudica*. Philippine Jour. Sci. C. Bot. **7**: 37-40.
- Brown, W. H.** ('16). The mechanism of movement and the duration of the effect of stimulation in the leaves of *Dionaea*. Am. Jour. Bot. **3**: 68-90. f. 1.
- Gardiner, W.** ('85). On the phenomena accompanying stimulation of gland-cells in the tentacles of *Drosera dichotoma*. Proc. Roy. Soc. **39**: 229-234.
- Fitting, H.** ('03). Untersuchungen über den Haptotropismus der Ranken. Jahrb. Wiss. Bot. **38**: 545-634.
- Hooker, H. D., Jr.** ('15). Hydrotropism in roots of *Lupinus albus*. Ann. Bot. **29**: 265-283.
- Hooker, H. D., Jr.** ('16). Physiological observations on *Drosera rotundifolia*. Bull. Torrey Club. **43**: 1-27. f. 1-11.
- Jost, L.** ('13). Vorlesungen über Pflanzenphysiologie. Dritte Auflage. Jena.
- Kraus, G.** ('82). Über die Wasserverteilung in der Pflanze. II. Der Zellsaft und seine Inhalte. Abh. Naturf. Ges. zu Halle **15**: 49-120.
- Noll, F.** ('88). Beitrag zur Kenntniss der physikalischen Vorgänge, welche den Reizkrümmungen zu Grunde liegen. Arb. Bot. Inst. Würzburg, **3**: 496-533. f. 1-4.
- Noll, F.** ('95). Über die Mechanik der Krümmungsbewegungen bei Pflanzen. Flora **81**: 36-87.
- Pfeffer, W.** ('06). The physiology of plants. Volume II. English translation. Oxford.
- Tunmann, O.** ('13). Pflanzenmikrochemie. Berlin.
- Vries, H. de** ('86). Über die Aggregation im Protoplasma von *Drosera rotundifolia*. Bot. Zeit. **44**: 1-11; 17-26; 33-43; 57-64.

SHEFFIELD SCIENTIFIC SCHOOL,
YALE UNIVERSITY